Reconstructing William Byrd's Music from Lute Book GB-Lbl Add. MS 31992: A Historical, Practical and Computer-based Approach

"Item: wheras I have many lute bookes prickt in Ciphers after the Spanish and Italian fashion and some in letters of A.B.C. accordinge to the English fashion, whereof divers are to bee plaid upon the lute alone and have noe singing partes, and divers lute bookes which have singing pts sett to them w^ch must be sunge to the lute and are bound in very good bookes and tied up with the lute parts, whereof some have two singinge bookes some three and some fower…"

The will of Edward Paston, d. 1630

As evident from his will, Edward Paston (1550-1630), a wealthy Catholic from East Anglia, amassed a diverse musical collection of which around one thousand vocal and instrumental pieces survive.[1] The music spans from the time of Josquin to that of William Byrd and is contained in a few dozen complete and incomplete partbook sets.[2] The circa five hundred lute intabulations are mostly arrangements of the music in the partbooks. They survive in five lutebooks that contain the sole settings of a number of well-known composers' vocal and instrumental works requiring polyphonic reconstruction to restore them into a performable state.[3] Reconstruction would allow this repertoire to be heard for the first time in over 500 years. For example, the material addressed in this article would potentially augment the existing repertoire of Byrd's consort songs by over 35 percent.[4] The aim of this article is to outline a new approach, involving computational analysis, that can make a significant contribution to the process of making idiomatic reconstructions of polyphonic music from lute intabulations.

To date this restoration work has not been fully carried out due to a series of challenges that these sources present. For instance, the lutebooks are notated in lute tablature which has inherent limitations (e.g. not indicating a specific pitch and providing limited rhythmic information). Nevertheless, some limited but valuable work reconstructing music from the Paston intabulations has been carried out. This includes Paul Doe's reconstructions of Robert White's Six Fantasias published in 1979,[5] which have been recorded by Fretwork and the Newberry Consort and performed by professional and amateur ensembles;[6] a testament to the importance of the repertoire in these lutebooks.[7] More recently, Volume 53 of Early English Church Music includes a reconstruction of Fayrfax's *Missa Sponsus amat sponsam*[8] which survives only in one of Paston's lutebooks (GB-Lbl Add. MSS 29246).[9] These reconstructed pieces complement the wealth of *opera omnia* and other major editions, but the fact that so little work has been carried out indicates the challenge of working with these sources.

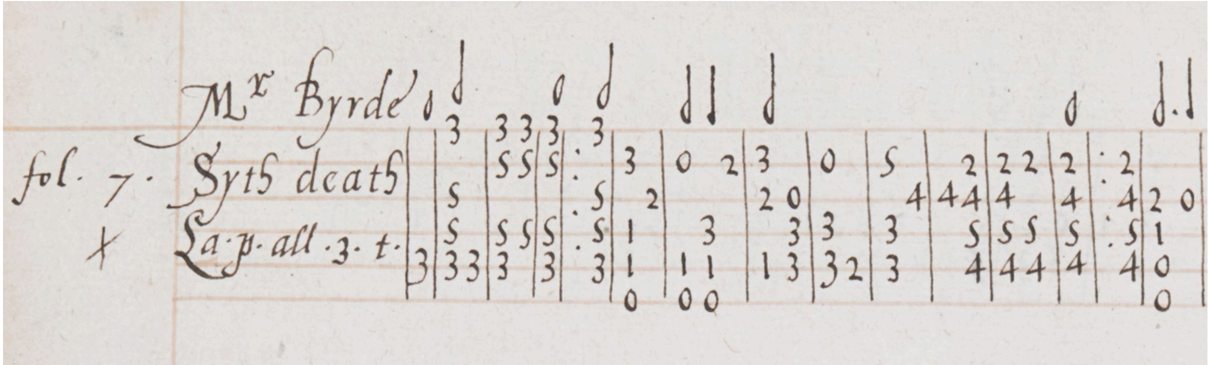
This study will offer a solution to these challenges and advance research in this area by introducing a combined approach that involves analysing team reconstructions and the use of technology to address the surviving pieces. Projects like *Tudor Partbooks* have introduced team reconstruction work, a process that also involves performance workshops to help evaluate reconstruction work, with good success.[10] However, despite these promising developments, this method tends to produce multiple solutions that can be difficult to evaluate.[11] To assist with the evaluation stage, the aim of this study is to demonstrate that computational analysis can be used to efficiently produce quantitative measures of aspects of the repertoire being reconstructed; multiple solutions to the reconstruction challenge can then be evaluated against these norms. In effect, this provides an efficient method by means of which we can evaluate whether a reconstruction's choice of key signature, instrumentation, ranges of different parts and the degree of overlap between them, are consistent with exemplars of the same genre. Computational analysis allows large corpora to be explored in ways that would be prohibitively time-consuming if done manually. The database created in the process of computational analysis can also be reused for future studies that may address different aspects of the repertoire. This computational analysis can therefore offer a valuable complement to existing team reconstruction methods and performance workshops.

The study will use a corpus of full settings and lute arrangements of Byrd's consort songs, and it will use the MIDI Toolbox to carry out three computer analyses.[12] First, it will assess the similarities between the original consort song settings and their lute arrangements, the latter from Paston sources. The purpose of this first analysis is to understand if the intabulations are reliable enough to be used for reconstruction work of those intabulations for which no other settings exist. Once this basic understanding is achieved, the second analysis will explore the discrepancies more thoroughly in order to provide new insights into the reconstruction work. The third and last analysis will evaluate three reconstructions of William Byrd's consort song 'In tower most high,' in GB-Lbl Add. MSS 31992 fol. 9v (one of Pastons lutebooks), with the assistance of the findings from the other two analyses. To my knowledge, this is the first time such an approach has been used for reconstruction work of this type.

The Paston Lutebooks and Tablature Notation

The main sources for this work are the five surviving Paston lutebooks: GB-Lbl Add. MSS 29246, 29247, 31992, GB-Ob MS Tenbury 340, and GB-Lcm 2089. They are unique in the context of English lute music since they were notated using Italian tablature notation, the one used by the Spanish vihuelists, as opposed to the French tablature notation used in England at the time. This means that with the exception of one rather amateur piece in Royal Appendix 76,[13] the five Paston lutebooks are the only surviving manuscripts of English origin notated in Italian tablature. That the lutebooks survive probably has to do with the fact that they were of little use to English lute players because of the foreign notation; we cannot say the same of the accompanying partbooks which are now lost. The Spanish connection runs even deeper since the pieces include rubrics in Spanish that indicate the note to be given to the singer, e.g. La p. all 3 t, which stands for: the first string on the third fret, see Figure 1. A few pieces contain a marginal rubric in Spanish 'Excelente,' indicating how much these pieces were enjoyed by the performers in the Paston household.

Figure 1: Start of Syth death by William Byrd as intabulated in GB-Lbl Add. MS 31992, fol. 3v. Note the rubric: La p. all 3 t (the first string on the third fret) indicating the note to be given to the singer. The figure also shows 'fol. 7r' as the folio for the accompanying singing partbooks, now lost.



Regarding the notation, in brief terms, the horizontal lines in Fig. 1 represent the strings of the lute (called courses as they come in pairs except for the first one which is single string) and the numbers represent the frets where the fingers are to be placed. In the Italian tablature used in the Paston books, the bottom line represents the top string of the instrument (highest in pitch). As an example, the first note in bar one of Fig. 1 is a 3 on the second string (an f_4 on a lute in G).

However, it is important to note that lute tablature is a graphical means to represent positions on the neck of the lute and not a specific pitch. Thus, the first note in 'Sith death at length' is an f_4 on a G-lute, but it can also be an e_4 on an F-lute; the pitch depends on the lute size used to create the lute arrangement.[14] For instance, parts for this piece survive in two sets of manuscripts one step apart. Thus, an A-lute can be used to perform the lute version in GB-Lbl Add. MS 31992 (31992 hereafter) accompanying the parts in GB-Lbl Add. MSS 29401-5 with no flats, or a G-lute can be used with the parts with two flats in US-CAh MS 30, see Fig. 2. In the end, there are a limited number of combinations based on the limited number of key signatures derived from the hexachords (i.e. no alterations in the key signature, one or two flats, or one sharp),[15] all of which exist in the Paston sources. Nevertheless, the challenge of finding what lute size to use on reconstructions of pieces that survive only as intabulations remains. This study therefore addresses this issue as well as some of the other uncertainties inherent in lute notation.

It is also worth noting that the Paston intabulations leave out the topmost part, i.e. the singing or top instrumental part.[16] This follows Continental practices such as the Spanish vihuela tradition and it means that the top parts need to be newly re-composed during reconstruction work. Re-composition escapes the scope of this study since the focus is to create a more critical reading of the intabulations as they are.[17] However, the topmost part is considered when deciding the overall range, individual ranges, and clef system for a piece being reconstructed. Figure 2 shows one of the pieces from the corpus in full, including the top singing part, the four viol parts, as well as the intabulation from 31992 with a literal transcription.

Figure 2: The start of Byrd's 'Sith death at length.' The parts are from US-CAh MS 30 with two flats. Note that the intabulation does not include the top line (superius). In addition, a literal transcription of the tablature is included as a departing point for reconstruction work.

Apart from not indicating specific pitch, lute tablature notation does not indicate the rhythmic duration for each note in a chord but simply uses the smallest rhythmic value. As can be seen on the third beat of Fig. 2, the bottom three parts (Tenor I, II and Bass) are indicated as minims in the intabulation even though they are semibreves. This means that when reconstructing such a piece without other surviving parts, the editor has to provide the correct part writing. This implies that some of the work is not reconstruction but re-composition, a distinction that was first articulated by Blezzard,[18] and that is apparent throughout this type of work.

Another idiosyncrasy of lute notation is that it does not indicate voice-crossings (or overlaps) for different parts, so these need to be worked out by the editor. In order to showing these limitations of lute notation, the transcriptions in this study only show one rhythmic flag per chord and do not attempt to provide any voice leading but simply stack the notes in each chord in the way they appear. This creates a more accurate representation of the notation, and is a better departing point for reconstruction work, particularly for those who may not be able to sight-read lute tablature.

The Corpus

This study focuses on the consort songs by William Byrd. The analyses utilise a combination of pieces for which both polyphonic settings and lute intabulations exist, in order to explore the relationship between the two, e.g. to measure how similar the intabulations and the full settings are. The available materials are shown in Table 1:

Table 1: Different settings of William Byrd's consort songs used in this study.

Item	Count/Source	Comments
Published consort songs settings by Byrd (modern edition)	41/Byrd Edition, vol. 15 (BE15)	Not all are complete, Brett used intabulations to reconstruct 9 of them
Paston intabulations of consort songs mentioned in BE15	24/GB-Lbl Add. MS 31992	25 but Brett suggested that 'The day delay'd' is not by Byrd
Consort songs surviving as full sets and intabulations (used to create corpus in Table 2)	14/Various	In 31992 and full sets in various manuscripts and publications (see BE15)
Reconstructed Consort Songs by P. Brett	9/BE15	Usually one part missing
'New' consort songs surviving only as intabulations	15/GB-Lbl Add. MS 31992	Not mentioned in BE15

Philip Brett used the Paston intabulations to reconstruct the missing parts for nine of the settings that survive incomplete. For instance, he extracted the Medius (treble viol part) for 'The Lord is my only support' (BE15 no. 2), the Medius (singing part) for 'Have mercy on us, Lord' and 'Lord, to thee I make my moan' (BE15 nos. 3 and 5), and the treble/tenor II/and bass viol parts in 'O God, but God' (BE15 no. 6).[19] Hence, one of the pieces reconstructed by Brett, 'The Lord is my only support' (BE15 no. 2), is used here to evaluate Brett's work using the method proposed in this study. Another addition to the corpus is the partsong 'O God, whom our offences' (BE16 no. 5), which was chosen to include a more homophonic and fully-texted part song. The total number of pieces in this corpus is sixteen, which are summarised in Table 2 below.

Table 2: Corpus of pieces considered for assisting and evaluating reconstruction work. The pieces are the fourteen consort songs by William Byrd that survive with parts and intabulations. In addition, two other pieces are added: the partsong 'O God, whom our offences', a more homophonic setting, and 'The Lord is my only support', in which the treble part was reconstructed by Philip Brett using the Paston intabulation.

Title	No/vol	Clef System	Key Sign/ Lute	Singing part	Clefs and ranges for parts 1-5					Comments
					P1	P2	P3	P4	P5	
Ah, golden hairs	13/15	High	0/A	P1	G2, g4-g5	C2, f#3-c5	C3, g3-g4	C4, c3-e4	F3, g2-a3	Predominantly homophonic
An aged dame	33/15	high	0/A	P1	G2, f#4-g5	C2, a3-d5	C3, f3-g4	C4, d3-g4	F3, a2-e4	P1 is singing part (G2), some more madrigalian writing, with some hints of staggered imitation.
As Caesar wept	14/15	high	0/A	P1	G2, f#4-g5	C2, g3-c5	C3, a3-g4	C4, d3-e4	F3, a2-a3	Range of a 7th in P3 but wider for P2. Classic CS example. More homophonic.
Blame I confess (Remember Lord)	15/15	Low	1/F	P1	C1, c4-eb5	C2, g3-bb4	C3, f3-f4	C4, c3-eb4	F4, f2-g3	Three staggered parts use imitation, a fourth hints at it.

Delight is dead	30/15	Low	2/G	P1/P2	C1, d4-eb5	C1, d4-eb5	C3, g3-bb4	C4, c3-f4	F4, f2-bb3	Top parts duet, same clefs and range. Bottom three parts intabulated. Range below the lute (only once). Staggered imitation in all parts.
In angel's weed	31/15	High	2/A	P1	G2, g4-g5	C2, c4-c5	C3, f3-eb4	C4, d3-eb4	F3, a2-bb3	Lute intab. starts from b.12. Slightly diff. ending because of repeat. Some imitation of the top part motives.
O God, whom our offences	5/16	Low	1/E	All	C1, d4-d5	C3, d3-g4	C3, d3-g4	C4, c3-d4	F4, f2-a3	A partsong. The two parts in C3 have identical ranges. More ornamented viol parts.
O Lord, bow down	7/15	high	2/A	P1	G2, d4-g5	C2, bb3-bb4	C3, f3-g4	C4, d3-f4	F3, a2-bb3	Top part with accompaniment structure and some imitation.
O Lord, how vain	8/15	high	2/A	P1	G2, f4-g5	C2, bb3-d5	C3, f3-g4	C3, f3-g4	F3, bb2-bb3	Problematic because the intabulation was done using a different setting. Same clef and range for P3-4. Imitation, duets.
O that we woeful wretches	9/15	High	2/A	P1	G2, f#4-g5	C2, c4-c5	C3, g3-g4	C4, c3-f4	F3, bb2-c4	Accompaniment plus top line structure. Some very short imitation.
Quis me statim	37/15	Low	1/F	P1	C1, c4-e5	C2, g3-a4	C3, d3-g4	C4, a2-d4	F4, f2-a3	The bass part goes down to an f2 several times, i.e. lower than the range of the lute. Accompaniment plus top line structure.
Rejoice unto the Lord (1586)	11/15	great compas s	0/G	P2	G2, d4-g5	C1, c4-d5	C3, g3-bb4	C4, c3-d4	F4, f2-a3	Bass goes down below the range of the lute 11 times (to a F2). All parts attempt imitation.
Sith Death at length	22/15	high	2/G	P1	G2, eb4-eb5	C2, bb3-bb4	C3, f3-g4	C4, f3-c4	F3, ab2-eb4	Very narrow range for P4 (perfect 5th). Some discrepancies in the last section. Simple melody with mostly homophonic imitation.
The Lord is my only support (Psalm 23)*	2/15	great compas s	2/G	P2	G2, f4-eb5*	C1, c4-eb5	C3, g3-g4	C4, d3-d4	F4, g2-bb3	*The treble part was reconstructed by Brett. Simple melody with some imitation (not all parts, best with bass)
The man is blest (Psalm 112)	4/15	great compas s	1/G	P1	G2, g4-eb5	C1, c4-c5	C3, g3-g4	C4, d3-c4	F4, f2-g3	A few imitation motives that are not copied by the singing part.
While Phoebus us'd to dwell (The noble famous Queen)	28/15	High	1/A	P1	G2, a4-g5	C2, c#4-d5	C3, g3-a4	C3, f3-g4	F3, c3-c4	Staggered more developed imitation in all parts.

The columns in Table 2 represent: 1) Piece title, 2) piece number and volume in the Byrd edition, 3) the clef systems based on Great Compass (clefs from G2-F4), and Morley's normal clefs (from C1 or C2 to F4) as well as

High Clefs (from G1 or G2 to C4). 4) The signature contains either no alterations (0), one (1) or two flats (2), and the pitch for the first course of the lute that works with that particular intabulation is also indicated. 5) The singing part for each consort song (either the top (P1) or second part (P2)). Columns 6-10 show the clef and range for each part. Column 11 includes noteworthy information that could have an effect on reconstruction work or accuracy calculations (e.g. having two parts with the same clef and range, or obvious discrepancies between the lute and original settings).

Table 2 shows a spread of representative pieces from the genre as there is a combination of different key signatures, piece lengths, as well as clefs and range combinations. The pieces also include various arrangements of internal clefs, such as 'O God, whom our offences' which contains internal parts that have identical clefs/ranges and which create challenges for reconstruction because of the lack of range differentiation between parts. There are also pieces that use imitation as well as more homophonic ones. The corpus of sixteen pieces represents nearly 40 percent of the fully surviving consort songs by Byrd, a representative sample of this repertoire.

There are a few instances in this corpus where the surviving parts are not completely compatible with the intabulations. There are various possible reasons as to why this is the case, e.g. the parts used to create the intabulation do not survive, or the intabulator introduced some ornamentation in the lute arrangements. However, the intabulations tend to be quite literal so the latter point is the exception. Some of these implications are discussed in more detail in a later section since they are relevant to the reconstruction work. In any case, it is pertinent to quantify the differences in order to know how much room for correction is appropriate within a reconstruction.

The need for this type of analysis responds to the challenges presented by this type of work. As Brett states in the preface to BE15: 'about a quarter of the songs in the present volume are incomplete,'[20] and some are 'unique to the book [31992] and therefore incapable of being fully reconstructed.'[21] In the end, fifteen consort song settings survive only as intabulations that were left unreconstructed by Brett.[22] The present study is an attempt to introduce a method to reduce some of these limitations in order to create informed reconstruction of this repertoire; the methods can then be applied to other repertoire in future work. In the end, adding fifteen new consort songs to Byrd's output would be a significant contribution, even more so when considering that some of the pieces have historical significance, e.g. 'Look and bow down', a six-part consort song with a text by Queen Elizabeth with references to the defeat of the Spanish Armada in 1588 (in 31992 fol. 43v).

Before moving to the analyses, it is important to note that one of the challenges of this type of research is the need for scores in digital format to complete the evaluations. However, there is excellent progress made on Optical Music Recognition (OMR) and Music Information Retrieval (MIR) from digital scores,[23] which attempt to automate some of these processes. For instance, projects like the Music Encoding Initiative (MEI) have helped define a schema for music notation encoding, Aruspix has advanced the OMR process of scanning early music scores, and the Electronic Corpus of Lute Music (ECOLM) has advanced the ability 'to store and make accessible to scholars, players and others, full-text encodings of sources of music for the Western-European lute (and other relevant sources).'[24] Based on some of this work, projects like Richard Freedman's 'Lost Voices,' have created digital transcriptions of French chansons from the publications of the Parisian printer Nicolas Du Chemin (active between 1549 and 1568) in different formats (PDF, MEI, etc), in addition to studying this repertoire more closely.[25] Freedman's work highlights the importance of a corpus approach in understanding a variety of issues, and this study adopts this approach by considering issues of reconstruction, re-composition, and performance practice. Furthermore, as more scholars share their corpora, the type of study attempted here will become easier to put together, thus advancing our ability to evaluate materials without having to create the corpora from scratch.

The discussion will now turn to the methods used and the analysis derived from this corpus. In the next two sections I outline a two-stage comparison between complete polyphonic parts and intabulations in the corpus, to establish the relationship we should expect between these formats in future reconstructions of one from the other. The third stage takes a different approach: we calculate different metrics including the ranges of parts and overlaps between them, and then compare three independent reconstructions of one song using these metrics. The different stages of analysis together demonstrate the utility of computational analysis in supporting other existing methods to reconstruction of this repertoire.

Analysis one: Similarities between the polyphonic parts and intabulations in the corpus

Lute manuscripts and prints can contain notational errors or editorial changes that have been the source of commentaries by early modern and current musicians and scholars. In a sense it is easier to justify errors in printed sources since it is possible that some of the printers could not read lute tablature and made mistakes when typesetting the music. A good example is the music of Melchiore Barberiis (1546-1549), which contains many errors despite coming from the influential press of Girolamo Scotto.[26] Composers/musicians such as John Dowland also complained about the corrupted versions of their pieces that were in circulation. Dowland stated in the preface of his popular *First Booke of Songs, 1597* that 'there have been divers Lute-lessons of mine lately printed without my knowledge, false and imperfect.'[27] Judging by the surviving manuscript sources of Dowland's music and their different readings of specific pieces, one can only imagine how much is lost.[28] From this context, it is natural to want to know how the Paston lute arrangements compare to the vocal or instrumental settings used for their creation. Thus, this first analysis looks at how similar the lute arrangements of Byrd's consort songs are in comparison to the original settings.

In order to measure the similarities between the intabulations and partbooks, this study proceeded in two stages. First, 'Discrepancy Scores' (DS) were calculated by dividing the number of discrepancies between the two sources by the total number of notes in the piece with the results presented as percentage values; this was done for each piece individually as well as for all the pieces in the corpus (mean DS). In the second stage, described in the next section, we employed more sophisticated measures to explore the relationships between the two sources in more detail. Both analyses employed the MIDI Toolbox, a computational environment that allows for multiple numerical and graphical representations of musical scores.[29]

As explained above, lute tablature notation is a shorthand for lute players that leaves many rhythmic and harmonic decisions in the hands of the performer, i.e. no indication of a specific pitch, rhythmic ambiguity due to having only one flag per chord, and the inability of tablature to indicate voice crossings or unisons. With this in mind, a few rules were created for the computer analysis:

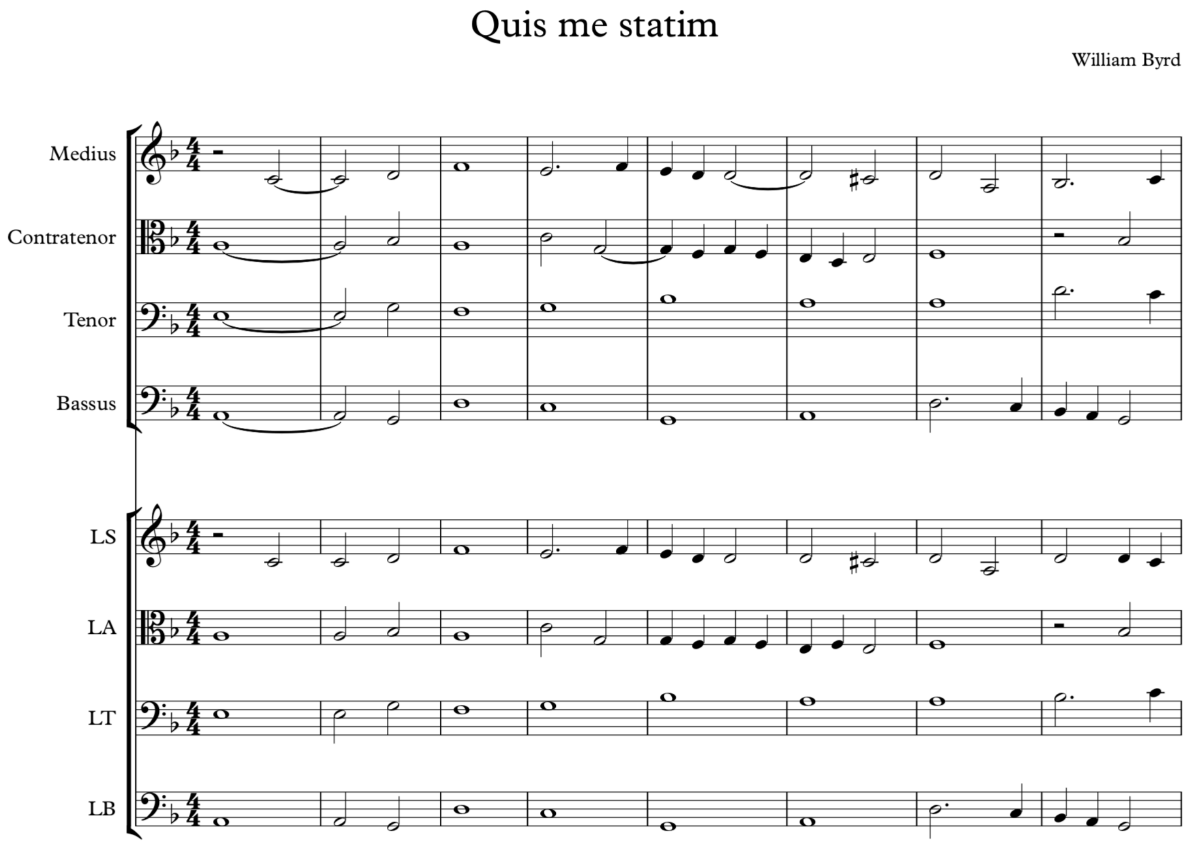
1. The intabulations were matched to the pitch of the viol parts by choosing an appropriate lute size.
2. The intabulations were separated into parts and matched to the original settings. This entailed matching rhythmic values when possible, whilst resolving discrepancies separately.
3. Discrepancies in the intabulations such as octave transpositions in the bass, semibreves split into two minims, and dotted rhythms (a dotted minim) presented as a long and short values (minim plus crotchet) were transcribed as they appeared in the intabulations and then quantified.

The purpose of these rules was to have a consistent baseline from which to create the scores and enable comparisons between the full settings and the intabulations. This was necessary because the process was not completely automated but required human intervention to prepare the scores. The process was as follows. First, the lute tablature transcriptions were created in Sibelius. Figure 3 shows the lute intabulation of Byrd's *Quis me statim* transcribed from 31992 fol. 38r. Second, the tablature was then pasted on to the staff above in order to create a literal transcription of the tablature with virtually no human intervention. As can be seen, Sibelius provided only one rhythmic value per chord, and the stems were removed to avoid any suggestion of voice-leading. The result is a more accurate view of the information provided by lute notation.

Figure 3: Intabulation and transcription of Byrd's *Quis me statim* (BE15 No.37) with literal transcription. A lute in F works with the parts with one flat in US-CA Harvard 30, GB-Lbl Add. MS 29401-5, and GB-Ob. Tenbury 369-73.

Third, the chords from the lute transcriptions were then separated into four different parts that were matched to the original parts using rule 2 above, which was where the majority of human intervention took place. When the parts did not match, the discrepant notes were assigned to the line that made musical sense. Figure 4 shows the two sets of parts, the original parts (Medius, Altus, Tenor, Bassus) and the ones extracted from the tablature (LS, LA, LT, LB) once the rules above were applied. Also note how a lute in F matches the pitch of the viol parts (rule 1 above).

Figure 4: Byrd's *Quis me statim* showing the lute intabulation separated into four parts in comparison to the viol parts. The 3rd beat of bar 4 shows how the voice crossing between the tenor and superius is not present in the intabulation.



For instance, bars 5 and 6 of Byrd’s *Quis statim* provide various scenarios on how the computer recorded differences: 1) the first crotchet in bar 5 is a four-part chord identical in both sets or parts, although the tied note in the Contratenor is not tied in the intabulation so this was recorded as a discrepancy by the algorithm, 2) the second, third and fourth crotchets in that bar are identical for both sets so nothing was recorded, 3) the first crotchet in bar 6 is a three-part chord for the viols but a four-part chord in the lute parts; this was recorded as a discrepancy because of the repeated D_4 in the top lute part. Note that with the exception of the D_3 in the Countertenor part (second crotchet of bar 6), which is an F_3 in the lute part, all of the discrepancies in this case have to do with notes tied across a bar. The analysis using an LDM algorithm gives the results shown in Table 3.

Table 3: Showing the discrepancy score (DS) for all the pieces in the corpus, i.e. a comparison between the fully surviving polyphonic settings and the Paston intabulations of the same pieces. The results are expressed as a percentage.

Name	Discrepancy Score (%)	Comments
Ah, golden hairs	9.38	
An aged dame	4.76	
As Caesar wept	6.71	
Blame I confess (Remember Lord)	9.09	
Delight is dead	5.59	
In angel’s weed	10.65	

O God, whom our offences	7.03	
O Lord, bow down	5.67	
O Lord, how vain**	11.39	The alto part for this piece is quite ornamented compared to the intabulation, thus creating a greater discrepancy.
O that we woeful wretches**	11.7	The intabulation was probably created using a different source, hence the high discrepancy.
Quis me statim	5.58	
Rejoice unto the Lord (1586)	11.13	
Sith Death at length	11.06	
The Lord is my only support (Psalm 23)**	3.23	The treble part was reconstructed from the intabulation by Brett, hence the low discrepancy score.
The man is blest (Psalm 112)	10.53	
While Phoebus us'd to dwell (The noble famous Queen)	5.55	
Total average	8.07	**6.42% if we eliminate these pieces.

The discrepancy score for all of the pieces was around 8 percent (or 6.4 percent when the problematic pieces mentioned above are taken out), which is a significant amount that will be investigated more closely in the next analysis. For now, it is important to note that some of the intabulations were created using different versions of the polyphonic settings available and this influenced the data. As stated in Paston's will: '…*and divers lute bookes which have singing pts sett to them w^{ch} must be sunge to the lute and are bound in very good bookes and tied up with the lute parts.'* The lutebooks include the foliation for accompanying partbooks, but none of the surviving partbooks in the collection match this foliation. Although the pieces appear in other partbooks, sometimes there are significant differences between the parts and intabulations, increasing the rate of errors in the analysis.

This was very clear in the case of 'O Lord, how vain' (11.39 percent DS) and 'O that we woeful wretches' (11.7 percent DS). The intabulation of 'O Lord how vain' is quite different from the surviving sets in GB-Lbl Add. MS 29401-5 and Christ Church, Mus. MSS 984–988 (the Dow partbooks).[30] Figure 5 shows some of the discrepancies between the various parts.

Figure 5: Bars 41-47 of 'O Lord how vain'. This piece has the lowest level of accuracy (82.66 percent) of the pieces used in this study. Notice the discrepancies between the lute (bottom four parts) and the viol parts (top), which suggests different versions of the piece.

Both settings are equally difficult to play, so it is clear that the two versions are simply different and not a simplification of the parts for the sake of performance. It is worth noting that the majority of the discrepancies occur in the last section of the piece which is usually repeated which means that perhaps there are some unclear performance practice implications of a more ornamented last section.

Simple note counts were carried out for each part using the MIDI Toolbox, which showed that in ‘O Lord how vain’ the Countertenor has 12.4 percent more notes than the intabulation, thus providing further indication that they are not from the same source. Curiously, the other parts in this piece are more similar (see Table 4 for information on all parts). This suggests that the Countertenor part may be a more ornamented part than the original or perhaps a later version from the one used to create the intabulation. In any case, the discrepancy in the parts had a negative effect in the discrepancy score calculations. In the case of ‘O that we woeful wretches,’ the note discrepancies are also high but more evenly spread between the two inner parts.

Table 4: Note count discrepancies for each part between the viol setting and intabulation of ‘O Lord how vain’

Note count difference	Medius	Countertenor	Tenor	Bassus
O Lord how vain	0%	12.4%	1.85%	2.17%
O that we woeful wretches	2.63%	8.93%	6.14%	1.6%

Conversely, ‘The Lord is my only support’ has the lowest discrepancy score in this study (3.23 percent). However, this is partly because the treble line was reconstructed by Brett using the Paston intabulation, although he did not completely respect the intabulation since the part he created is different from the intabulation by 1.32 percent. If we account for these unusual pieces by eliminating them from the discrepancy score calculation, then we have a slightly better 6.42 percent average for the group in Table 3.

Another point worth noting is that the degree of discrepancy between the outer parts (Medius and Bassus) is higher, indicating that this is a good starting point for reconstruction work. Table 5 shows the averages for all sixteen pieces in the corpus.

Table 5: Discrepancy score by part based on the corpus of sixteen pieces.

Part	DS for the 16 pieces (%)
Medius	**5.96**
Countertenor	**10.25**
Tenor	**11.04**
Bassus	**5.04**

As can be seen, the inner parts (Countertenor and Tenor) are 10 to 11 percent different, and the outer parts (Treble and Bass) are 5 to 6 percent different when comparing the original settings to the intabulations. This suggests that the former ones need more attention during reconstruction work due to their higher discrepancy score. The next section discusses in more detail how the 6 to 8 percent discrepancy can be used to assist the process of reconstruction.

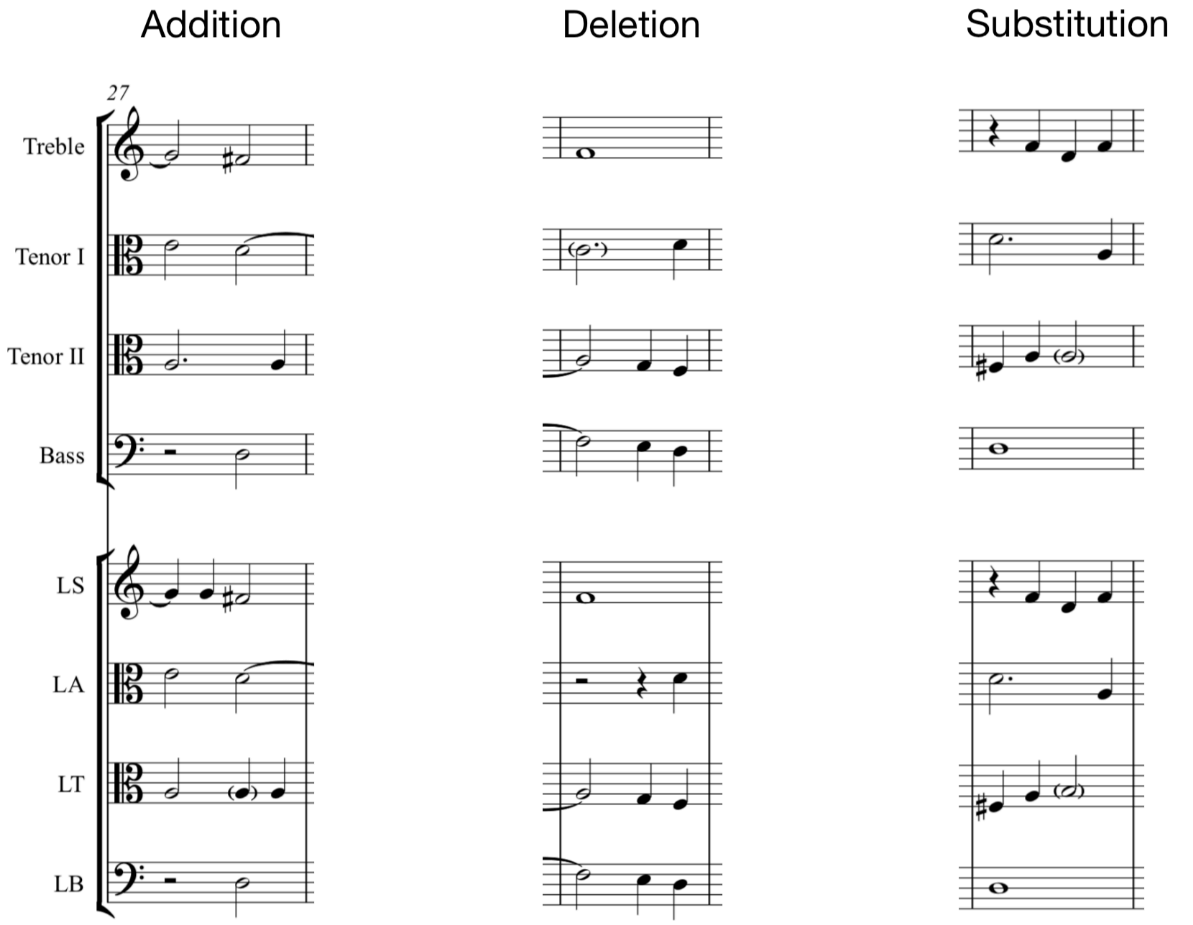
Analysis two: Accounting for the differences between partbooks and intabulations

The first analysis gave a basic understanding on how similar the intabulations and parts are. For this second analysis, the challenge was to investigate more closely the 6 to 8 percent discrepancy score in order to find patterns to help remove some of the uncertainties presented by this reconstruction work. This stage also employed MIDI Toolbox and an algorithm was used to compare pairs of parts by looking at the differences in the sequences of pitches through string edit distance and dynamic matching.[31] This comparison utilised the Levenshtein Distance Metric (LDM), a measurement used to compare two strings of information, in this case matching pairs of parts from all the pieces in the corpus. The LDM measured all of the intervallic and rhythmic differences between the two sets of music, and it provided very good granularity since it was able to identify three different types of discrepancies: the rates of deletion, addition, and substitution. Taking the viol parts as the ‘original’ version of the piece to be compared against the intabulations, the LDM provided three measurements:

1. Deletion: A note in the original parts (the viol parts) is not in the lute intabulation
2. Substitution: Same number of notes in both sets of parts but with pitch discrepancies
3. Addition: The lute part has a note that is not in the viol parts

The application of the three possibilities is shown in three different excerpts from Byrd’s ‘Rejoice unto the Lord’ (BE15 No. 11), see Figure 6. Bar 27 shows an instance of addition, the lute tenor part (LT) has a crotchet A_3 in the third beat which does not appear in the viol part (Tenor II). Bar 39 shows an instance of deletion, the dotted minim C_4 in the first beat of the viol part (Tenor I) is not in the lute alto part (LA). Finally, bar 82 shows a substitution in beat 3, the A_3 in the viol part (Tenor II) is a B_3 in the lute part (LT).

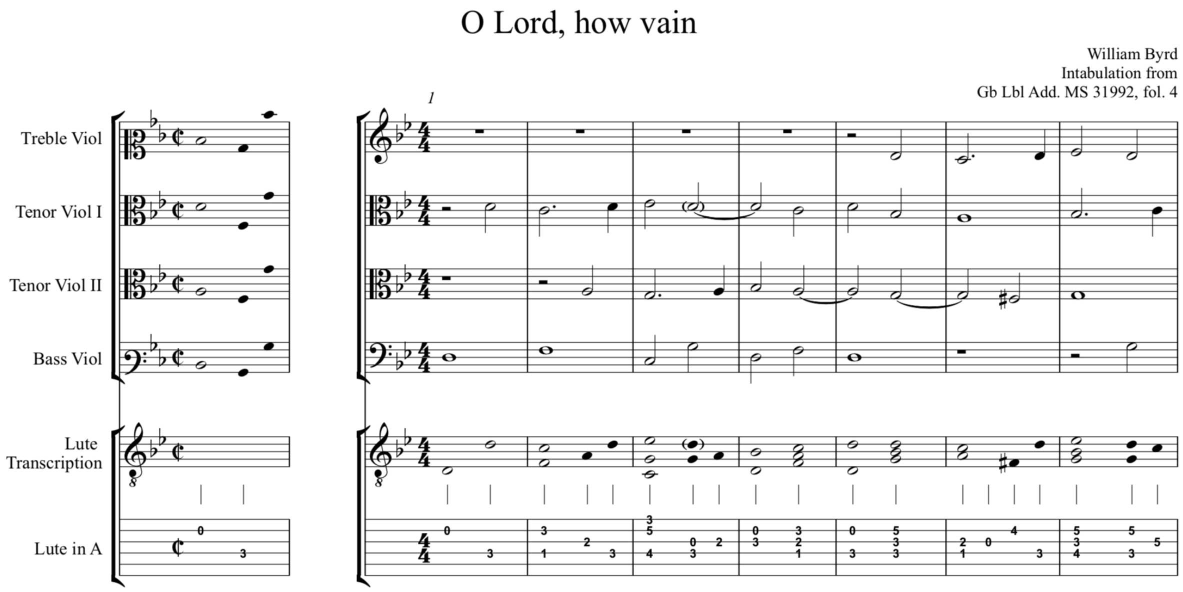
Figure 6: Instances of addition (bar 27), deletion (bar 39), and substitution (bar 82) in Byrd's 'Rejoice unto the Lord' (BE15 No.11). Note that the baring matches the one in the intabulation (bars are subdivided in half).



This more granular approach allowed us to quantify the discrepancy score from analysis one in more relevant terms. For instance, when doing these reconstructions, some of the editorial decisions deriving from the intabulations could be easily spotted, e.g. holding suspensions until they resolve across a bar, or finding the right voicings for a sequence of four-part chords. However, more thought and deliberation are required for certain discrepancies and therefore some of these were investigated. For instance, holding a long note across a bar (other than a suspension) relates to the rate of deletion. Changes in the tablature due to the physical limitations of the instrument are also important; this relates to the rate of substitution. Another issue investigated was what percentage of the notes in the bass part needed to be transposed up an octave in some instances, which also relate to the rate of substitutions.

First, we wanted to know how much of the discrepancy score was accounted for by notes that go across a bar (other than suspensions) since tablature does not indicate this in a consistent way. This in turn gives an idea of how to treat this feature during reconstruction work. Figure 7 shows a couple of discrepancies between the viol parts and the lute transcription in Byrd's 'O Lord, how vain' (BE15 No.8). For instance, bar three of the intabulation indicates the D_4 as a crotchet instead of two tied minims as in the Tenor I viol part. In this case the melodic contour suggests that the note should be a semibreve (two tied minims) but this is not always the case, leaving the decision to whoever is doing the reconstruction. In the end, quantifying these occurrences helped us understand how to handle these idiosyncrasies of lute notation during reconstruction work.[32]

Figure 7: The start of Byrd's 'O Lord how vain' [BE15 No.8], the viol parts on top and a transcription of the lute intabulation below. Note how in the third bar of the lute transcription, the D_5 appears as a crotchet instead of two tied minims as in the viol part above (Tenor Viol I). In this case the flow of the line strongly suggests the semibreve, but this is not always the case.



The process involved comparing two different sets of scores, one with the ties across bars silently corrected (as per the viol parts), and the other with no ties across bars (as they appear in the intabulations). The first group has a deletion rate of 2.3 and the second 5.35 (the difference between these two groups is 3.05). This difference is indicative of the ambiguity created by tablature notation and gives an empirical measure of what can cause potential errors during reconstruction work.

Naturally, one can even look at subgroups within the corpus, and this is our second example. For instance, it becomes apparent that pieces with the same internal clefs (e.g. C3 for two of the parts) can show high rates of substitutions because the music does not fit the instrument and therefore it seems that changes were made by whoever created the intabulation in the Paston household. The three pieces in the corpus that have the same internal clefs are 'O God whom my offences' (BE16 no.5, a partsong), 'O Lord how vain,' (BE15 no.8), and 'While Phoebus' (BE15 no.28), which are summarised in Table 6.

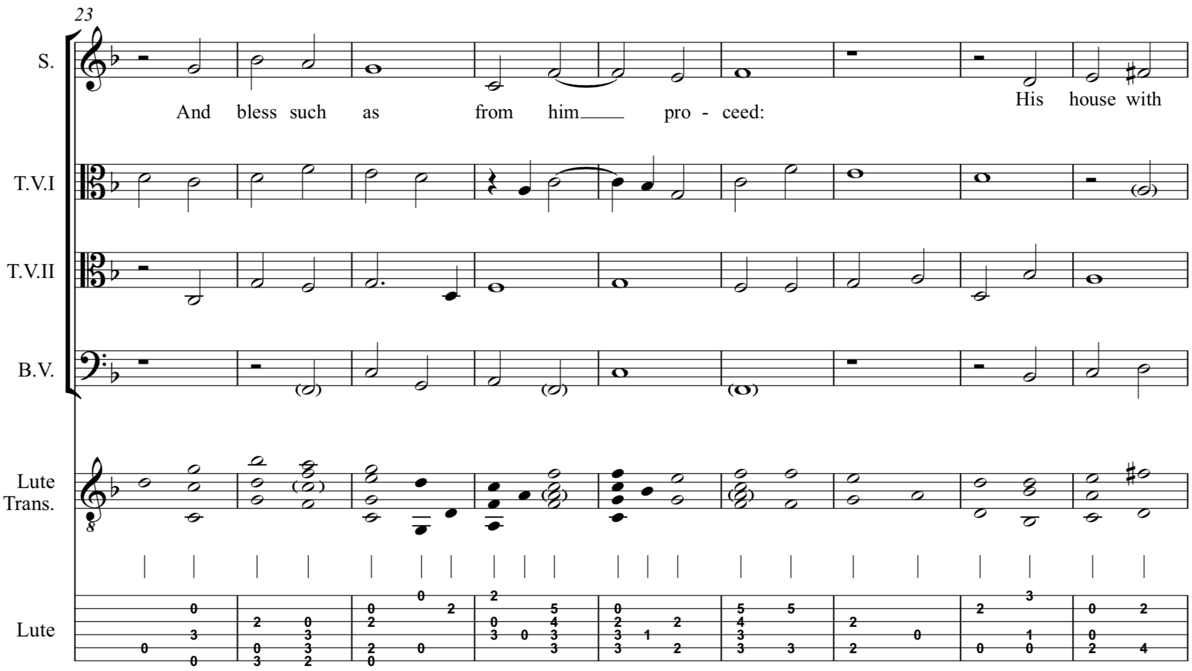
Table 6: Pieces with identical internal parts in the corpus.

Piece	Internal clefs	Observations
O God whom my offences (Partsong)	C3, d3-g4 (Medius) C3, d3-g4 (Countertenor)	Identical clef and range for Medius and Countertenor parts. However, the rate of substitution is high (3.67 percent) in the Tenor part instead, suggesting that this part was intabulated last thus requiring changes to fit the lute.
O Lord how vain	C3, f3-g4 (Medius) C3, f3-g4 (Countertenor)	Identical clef and range for Medius and Countertenor parts. The rate of substitution for the outer parts is zero, but the CT and Tenor have high rates of substitution (4.90 and 4.76 percent respectively). However, this case is deceptive since, as mentioned before, the intabulation was created using a different set of parts.
While Phoebus	C3, g3-a4 (Countertenor) C3, f3-g4 (Tenor)	Same clef but slightly different ranges for CT and Tenor. The rate of substitution is 4.4 percent for the Tenor part suggesting that this part needed to be changed to fit the lute.

At least in the case of 'O God whom my offences' and 'While Phoebus' the substitutions suggest the necessity to change notes in the intabulation to make the music work on the lute. However, it is worth pointing out that these are extreme cases that account for a very small percentage of the discrepancies. Examples of other subgroups that could be analysed more closely include music in the great compass or pieces that use imitation.

As previously mentioned, the analysis shows that bass parts tend to be highly similar. However, if substitution rates are high in the bass part, this usually indicates that the lowest notes in the part are transposed up an octave, which is a specific case that occurs in music in the great compass (the outer parts use F4 and G2 clefs). As implied in the name, pieces in the great compass cover the entire Gamut (G_2 to G_5) and therefore cannot be transposed. In addition, they are almost always intabulated for a lute in G since the instrument covers the Gamut. Therefore, if the range for the bass part goes below G_2 (the lowest note on a six-course lute in G), these notes need to be transposed up an octave.[33] The most obvious example of this was 'The man is blest' (BE15 no.4), a piece in Great Compass with one flat in the signature and 10.39 percent substitution rate in the bass line.[34] Figure 8 shows how the Fs are transposed up an octave on bars 24, 26 and 28. In many instances this causes changes to the internal parts since the arranger is adding more idiomatic chords (see notes in parenthesis in the transcription).

Figure 8: Byrd's 'The man is blest.' Notice how the low F_2 in the bass part (second minim of bar 24) is transposed up an octave in the lute intabulation. This causes changes in the inner parts, e.g. the C_4 is added to the lute part.



It is worth noting that there are only eight consort songs by Byrd in the great compass. Of these, only three go below G_2 in the bass, and pieces in the great compass tend to be an octave range for each part (e.g. G_2 to G_3 in the bass). The other two pieces in this group are 'Rejoice unto the Lord' (BE15 no. 11) and 'Thou poets' friend' (BE15 no. 24). The former maintains a range of an octave and a second in the bass (F_2-G_3) and a 6.07 percent rate of substitution, and the latter only uses the F_2 once (there is no substitution rate for this piece since no intabulation survives to make the comparison). In the end, if the range of the bass in a reconstruction is under an octave and the overall range of the piece tends towards three octaves, there is a good chance that the music should be reconstructed using the great compass and that some notes will have to be transposed down the octave, which will become clearer in the discussion of ranges in the next section.

The rate of additions is also significant in various ways. For instance, there are instances where extra notes are added to a chord, e.g. a two-part section may suddenly have three parts, which happens when chords are idiomatic to the lute. More notes tend to be added to the inner parts in order to create more idiomatic voicings (the mean for all of the parts from lowest to highest is 0.98, 4.41, 4.79, and 2.03). A more common occurrence is when a dotted minim is presented in tablature as a minim plus a crotchet. In fact, the beginning of Robert White's Fantasia I is a good place where the tablature can be amended into a dotted minim (Fig. 9).

Figure 9: Reconstruction of Robert White's Fantasia I. The three parts reconstructed by Paul Doe (top three parts), and a slightly different start (bottom three parts labelled Lute Altus, Lute Tenor, Lute Bassus), starting with a dotted minim instead of a minim and a crotchet, based on the findings from this study.

In this figure, the top three parts are from the reconstruction by Paul Doe with one sharp.[35] The next three lines are my suggested interpretation with one flat and starting with a dotted minim instead of minim plus crotchet as in Doe's work; there is almost no music with one sharp in the Paston sources hence the transposition down a step using low clefs. The compiled data support these simple but relevant changes, and it is worth noting that there are other range/clef implications that support using one flat and a lute in F, as will be explained in the next analysis.

In the end, this analysis shows how a data-driven approach to reconstruction from tablature helps to identify idiosyncrasies of the notation that can be analysed to minimise some of the guess work. An added bonus is that these irregularities can be identified very quickly and transparently, without the need to study a whole volume of music, and the queries can be refined depending on the needs of a specific task. What follows is an introduction to reconstructing one of the consort songs in the Paston collection in order to demonstrate the usefulness of this approach.

Analysis three: Reconstructing Byrd's 'In tower most high' from GB-Lbl Add. MS 31992, fol. 9v

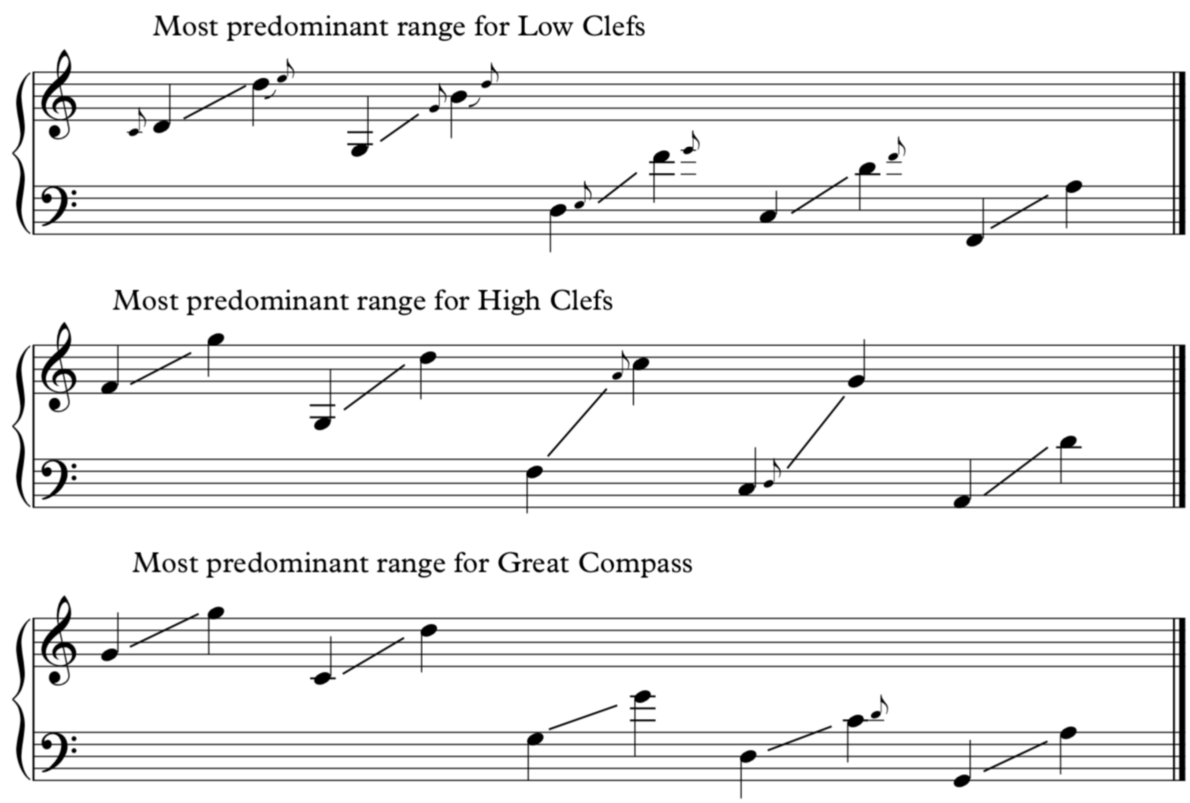
'heere are divers songs, which being originally made for instruments to expresse the harmony, & one voyce to pronounce the dittie, are now framed in all parts for voyces to sing the same. If thou desire songs of small compasse and fit for the reach of most voyces, here are most in number of that sort.'[36]

William Byrd, Epistle to the Reader in

This section will explore the reconstruction of Byrd's 'In tower most high', by subjecting three recent reconstructions of this piece to computational analysis to measure the extent to which they resemble examples of the target genre in terms of their clefs, ranges of individual parts and overlaps between these ranges. This work also helps identify the most appropriate lute for the reconstruction as well as the part(s) that do not use imitation. The reconstructions are referred to in the analysis simply as reconstructions A, B and C: they were created independently by three specialists in this repertoire.[37]

Byrd's 'Epistle to the Reader' shows his acute awareness of the vocal and instrumental idioms through the use of different ranges and clefs for each part, as well as his intention to reach the masses by providing some music of 'small compasse' (narrow range) comprising pieces 'fit for the reach of most voyces.' The excerpt above also reveals a different treatment for consort song and part song. These distinctions become essential when doing reconstruction work and therefore a closer look at the ranges and clef systems for the forty-one consort songs by William Byrd (in BE15) provides valuable information for this third analysis. Twenty of the consort songs are in high clefs (from G1 or G2 to C4), twelve in low clefs (from C1 or C2 to F4), and eight in great compass (clefs from G2 to F4).[38] In general terms, the consort songs in low and high clefs have parts with wider ranges (around an octave plus a fourth) but narrower overall ranges (two octaves and a sixth), whereas the pieces in great compass have parts with ranges of an octave and a wider overall range of three octaves. The obvious implication is that consort songs have more overlapping ranges. Figure 10 shows the most prominent ranges for each part and clef system.

Figure 10: The most predominant ranges for the forty-one consort songs by William Byrd.



Obviously, there are some exceptions to the ranges in figure 10. The two more prominent diversions are 'Out of the Orient crystal skies' (BE15 no.10) and 'Fair Britain Isle' (BE15 no.34) both with a wide overall range of three octaves (f_2 to f_5), and three octaves and a second (g_2 to a_5) respectively. Both of these pieces could be in great compass, but their internal parts are usually too wide (larger than an octave) which means they behave more like hybrid pieces. However, despite the exceptions, understanding the tendencies is crucial to the reconstruction work.

The behaviour of these two pieces is more like the pieces in *Psalms, Sonets, and Songes* (PSS, 1599). This compendium is not a good place to understand Byrd's clefs and ranges because of the diversity of genres arranged for singers. Many of the settings are hybrid, i.e. they do not show clear patterns of range and clef system. This is why looking at a more homogeneous group, such as the consort songs, reveals a more consistent treatment.

For instance, a piece in PSS such as 'Come to me grief' (high clefs, BE12 no.34), has parts that are close to an octave except the tenor which has an octave plus a third. 'Even from the depth' (low clefs, BE12 no.10) is similar but this time the countertenor has a range of an octave plus a fifth. 'Help Lord, for wasted are those men' (BE12 no.7) is a piece in great compass with a more characteristic range of an octave or an octave and a second for each part. However, 'How shall a young man prone to ill' (BE12 no.4) is a piece in great compass but this time the ranges are mixed. As implied in his epistle to the volume, Byrd simply compiled some of his works, added texts to all of the parts, and published the outcome in hope of pleasing a large number of interested people.

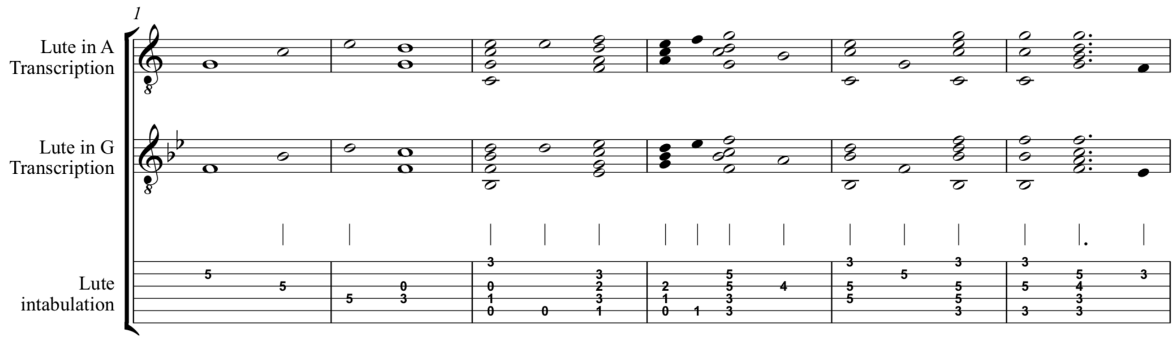
This section so far has demonstrated Byrd's consistency in his use of clef systems and ranges in his consort songs. The next step is to investigate how the computer analyses affect the reconstructions, which involves analysing three independent reconstructions of 'In tower most high' (31992 fol. 9v).[39] Three different elements will be addressed, 1) what lute size should be assumed for the reconstruction as this affects the ranges of the parts as shown above, 2) how voice overlaps work since these are not clearly presented in tablature notation, and 3) how the reconstructions compare against the corpus.

Keeping in mind the average ranges from Figure 10, the lutes that work for a reconstruction of 'In tower most high' are a lute in G which works with parts with two flats, or a lute in A which works with parts with no flats. The other alternatives would be a lute in C that would generate parts with one flat that are too high (the singing part lowest note would be a d_3 and the top a c_6), and a lute in D that would produce even higher parts.[40] This means that the more sensible alternatives are the G and A lutes. With regards to the ranges, a lute in G is the one used for music in great compass (as it covers the Gamut), and a lute in A is usually used for music in high clefs. This means that if the parts extracted work best with ranges of an octave, the G lute is the best choice (great compass). If the parts go beyond the octave, then the A lute is the best choice. Figure 11 shows a few bars of a literal transcription of the intabulation using these two lutes.

Figure 11: Literal transcriptions of Byrd's 'In tower most high' for lutes in A and G.

In tower most high

William Byrd
From GB-Lbl Add. MS 31992, fol. 9v



Since around 80 percent of the consort songs are in either low or high clefs, it is probable that this setting should be in high clefs with wider ranges for each part instead of in great compass. This is also an obvious choice since the parts are for viols and therefore a restricted range of an octave is not necessary; the implication then is a lute in A for this reconstruction.

The piece of evidence that helps cement the choice of lute is the fact that the manuscript in question (31992) is organised by clefs.[41] The section that includes ‘In tower most high’ contains only pieces in high clefs. For instance, seven of the pieces around ‘In tower most high’ are from *Psalmes, Sonets and Songes of Sadness and Pietie* (1588) and are all in high clefs for a lute in A, see Table 7.

Table 7: The pieces in 31992 around ‘In tower most high.’ Notice how all of the full settings are in high clefs, and they work with the intabulations when played with a lute in A.

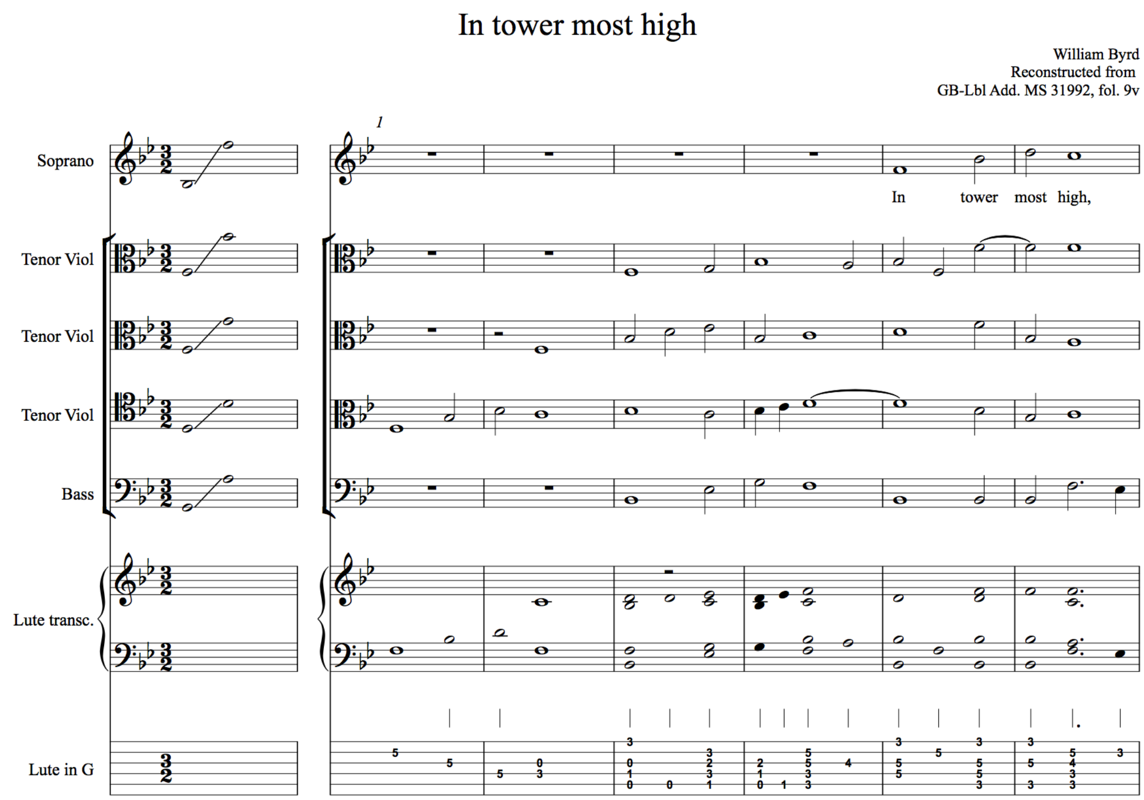
Piece	Flats	Clefs	Range for each part
As I beheld (fol.8v)	0	G2-C2-C2-C4-F3	g4-g5; b3-d5; e3-c5; c3-g4; a2-c4
Who likes to love (9v)	0	G2-C2-C3-C4-F3	g4-g5; c4-c5; f3-g4; d3-g4; a2-c4
In tower most high (9v)	N/A	N/A	N/A
Though Amarillis (10r)	0	G2-C1-C2-C3-F3	g4-g5; a3-d5; g3-d5; d2-g4; a2-d4
O happy Thryse (10v)	Fragment	See BE12.	
In fields abroad (11r)	1	G2-C2-C3-C4-F3	f4-g5; g3-c5; d3-g4; c3-d4; bb2-bb3
My mind to me (11v)	1	G2-C2-C2-C4-F3	f4-g5; a3-c5; f3-c5; f3-c5; a2-d4
When first by force (11v) (I that sometime)*	0	G2-C2-C3-C4-F3	g4-a5; a3-d5; a3-a4; e3-f4; c3-c4;
Where fancy fond (12r)	0	G2-C2-C3-C4-F3	d4-g5; g3-c5; e3-a4; c3-f4; a2-a3

*‘When first by force’ survives in two Paston sources, US-CA Harvard Mus 30 and Gb-Lbl Add. MS 29401-5 in high clefs and no flats (this is the version used in the table). It also survives in *Songs of Sundrie Natures* (1589) in high clefs with two flats (i.e. transposed down a step).

The table shows how this group of pieces have identical clefs in the outer parts (framing a high-clefs distribution) and a few different combinations of clefs in the inner parts. The ranges are mixed since most parts extend beyond the octave, with a few in the octave range, and none narrower than an octave. ‘Who likes to love’ and ‘When first by force’ have two parts at an octave (or an octave and a second). The former was probably conceived as a duet for superius and medius in imitation (the two parts with an octave range) plus a homophonic accompaniment provided by the countertenor, tenor, and bassus parts (with wider ranges). Overall, the group shows a few different approaches to composition by Byrd. Compositionally the closest match to ‘In tower most high’ is ‘My mind to me a kingdom is’ since there is imitation at the start in all but the bassus part. This latter piece has ranges beyond the octave for all but the top part, which has been labelled by Byrd as ‘the first singing part.’

All of this information strongly suggests that a reconstruction of ‘In tower most high’ should be done in high clefs with no flats and thinking of a lute in A. The internal clefs will be a combination of the internal clefs in Table 7 depending on the outputs. All or most of the parts will have ranges larger than the octave, but the top singing part follows the imitation but with a narrower range of an octave or an octave plus a second. This is significantly different to what was done in the three reconstructions. For instance, the three reconstructions were done thinking of a lute in G (using two flats), since this is the most common size to assume.[42] Furthermore, only in two of the reconstructions the range of the parts stayed within the octave suggesting a piece in great compass (RecB and RecC below). The third one has much wider ranges suggesting music in high clefs (RecA). Figure 12 shows the beginning of one of the reconstructions before the analysis.

Figure 12: Beginning of a reconstruction of ‘In tower most high’ before considering any of the data. The piece survives only as a tablature in 31992, fol. 9v.



As can be seen in Figure 12, the piece was intabulated with two flats and in great compass. The ranges hover around the octave except the top two parts (with an octave plus a fifth for the superious and an octave and a fourth for the medius). Since at least one of these parts is the singing part, they should be the ones that have a narrower range, but this was not considered in this particular reconstruction before the analysis. Table 8 summarises the clefs and ranges for three reconstructions prior to the analysis.

Table 8: Characteristics in the three reconstructions of 'In tower most high.' All of them done for a lute in G.

Recons. No.	Clefs/Ranges*	Ranges**	Comments
RecA	(G2)-C3-C3-C4-F4	F_3-Bb_4; C_3-F_4; F_3-F_4; G_2-C_4	Much wider ranges except Tenor
RecB	(G2)-C2-C3-C4-F4	A_3-Bb_4; F_3-G_4; D_3-Eb_4; G_2-Bb_3	Bass line with wider range
RecC (fig12)	(G2)-C3-C3-C4-F4	F_3-G_4; F_3-G_4; D_3-F_4; G_2-A_3	Ranges closest to great compass (octave)

*The clef for the Superious (in parenthesis) is speculative since this part is not in the intabulation and has to be newly composed.
**Only the ranges for the bottom four parts (the ones in the intabulation) are included.

The three reconstructions show similar approaches overall, at least in their clef arrangements. However, all of them use different ranges in different parts with only RecC staying closer to the prescribed range of the great compass (an octave plus a second).

Before seeing the rest of the data on these reconstructions it is worth presenting one more type of valuable data to be analysed. Voice crossings between parts are a good indicator of how the parts interact and how their ranges behave. For instance, the percentage of crossings between two parts can be measured and compared based on different clefs arrangements such as two internal parts in C3, or one in C3 and another one in C4. This gives an empirical measurement that can be used during reconstruction; Table 9 shows the average of overlaps between different parts for music in the corpus, although individual pieces or smaller groups that relate more closely to 'In tower most high' can also be assessed.

Table 9: Voice overlaps between different parts for pieces in the corpus.

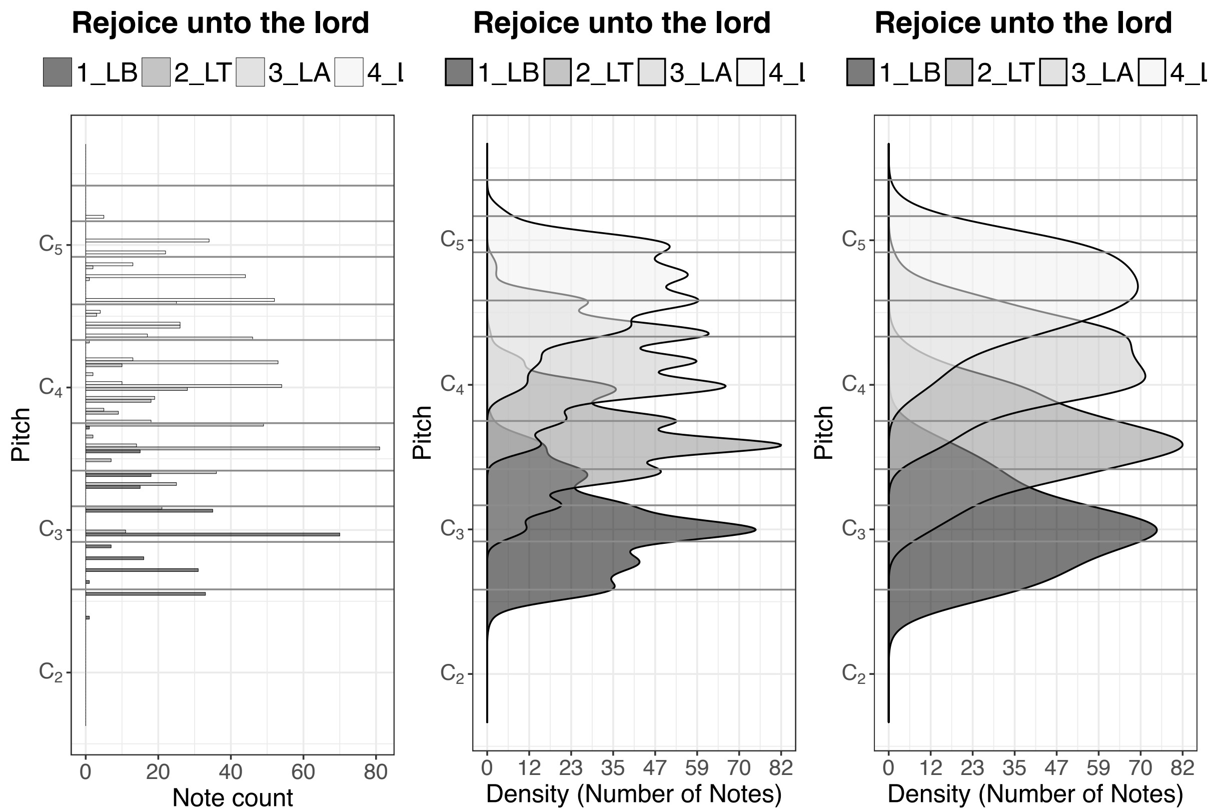
Parts	Average Overlap (%)
Bassus-Tenor	8.38
Tenor-Countertenor	23.58
Countertenor-Medius	14.67

The data shows that the internal parts have a higher percentage of overlaps (tenor and countertenor). This is partly due to the fact that these two parts have the highest tendency to have the same clef.

For instance, 'As Caesar wept (BE15 no.14) has the highest overlap rate (16.43 percent) between bassus and tenor (F4 and C4 clefs respectively) with an overlap of a fifth between the two parts. 'While Phoebus' (BE15 no.28) has the highest overlap rate (57.8 percent) between tenor and countertenor (same clef and almost identical ranges for the two parts: C3 with a range F_3-G_4 and G_3-A_4 respectively). 'Quis me statim' (BE15 no.37) has the highest overlap rate (23.04 percent) between countertenor and medius (C3 and C2 clefs with ranges of D_3-G_4 (octave plus a fourth) and G_3-A_4 (octave plus a second) respectively). In addition, the piece with the highest rate of overlaps is 'O God whom my offences,' (BE11 no.5) 24.58 percent, which is not surprising since the piece is the partsong included for comparison to the consort songs. Obviously, overlapping of parts are a feature of more homophonic fully texted songs as opposed to the consort songs. The consort song with the largest rate of overlaps is 'While Phoebus' (BE15 no.28) 22.06 percent, a piece that uses imitation in a similar fashion as 'In tower most high,' and thus could serve as a model for its reconstruction. 'While Phoebus' is in high clefs (the exact same clefs from Table 7), although the ranges are more like a piece in great compass (a more hybrid approach). Uncharacteristically, the top singing part has a narrow range of a seventh, which cannot be the case in 'In tower most high' since the imitation motive at the start extends to an octave.

Overlaps can also be spotted using graphical means since computational tools allow for data to be graphed easily. The graphs allow for similarities to be spotted quickly so that specific groups can be compared; see Figure 13 for three different ways of representing the data graphically.

Figure 13: From left to right, 1) the note count showing exact pitches in all four parts of 'Rejoice unto the Lord'; notice that the overlaps between parts are not easy to discern. 2) A density graph extrapolated from the first one (with .85 standard deviation) shows range overlaps much better. 3) Shows an even smoother representation (with 1.5 standard deviation) but at this point the information becomes too inaccurate (e.g. there seem to be an overlap between the LB and LS parts which does not exist).

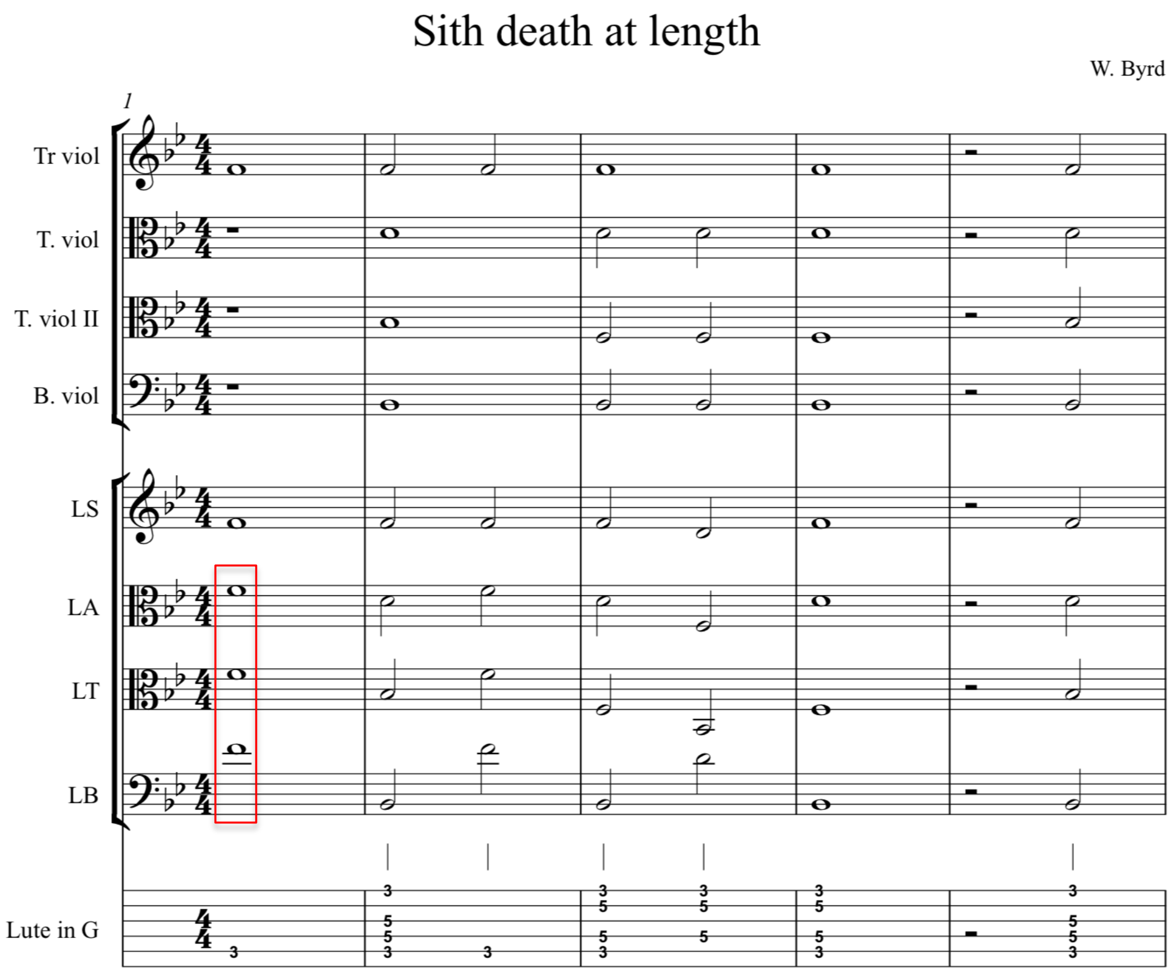


The first graph on the left shows the note count (how many times a pitch appears in the piece by individual part). For instance, the pitch C_4 appears at least ten times in three of the parts (LT, LA, LS) causing a triple overlap. Similarly, there are other places with similar overlaps that can be compared to either other pieces or the pieces being reconstructed. The note frequencies can also be smoothed for visual purposes which makes seeing the overlaps much easier. This is done by altering the standard deviation of the density graph as in the middle (.85SD) and right (1.5SD) graphs. The higher the standard deviation, the less accurate the reading is, e.g. in the graph on the right there seems to be an overlap between the LS and LB parts that is not real. In any case, such diagnostic graphs are a useful visual aid that can facilitate comparison.

The previous two analyses prove very useful when comparisons between the corpus and intabulations are made. However, the data cannot be used in the last analysis because the first two analyses compare the intabulations against the original settings, but these do not survive for the final analysis of the reconstructions, which means that there is nothing to compare against. Hence, for this last analysis, a new set of data was gathered from the scores in the corpus in order to compare them to the reconstructions.

The process entailed extracting four different parts from each intabulation using the exploding algorithm in Sibelius.[43] This Sibelius feature allows users to take music from a single staff, e.g. a lute transcription, and paste it into four different staves. The process works well at extracting four-part chords, as there is information for every part, however chords with fewer than four notes are problematic. For instance, if a beat has only one note for all four parts, e.g. a note in the alto part with all other parts having rests, the algorithm will add that note to all parts as potential candidates. Basically, the algorithm does not know what part the note belongs to, so it includes it in all the parts. Figure 14 shows the issue with the exploding algorithm in Sibelius.

Figure 14: The start of 'Sith death at length' with the original parts on top and the extracted parts from the intabulation extracted using Sibelius exploding algorithm. Notice how Sibelius adds extra notes, e.g. the F_4 from the Treble Viol part in bar 1 is added to all the other parts by the algorithm.



As shown in Figure 14 (bar 1), instead of rests, the exploding algorithm in Sibelius adds the F_4 from the LS part to the other parts. Despite this flaw, using this functionality from Sibelius creates consistent data that is free from human intervention, resulting in the possibility of measuring the reconstructions of 'In tower most high' against its intabulation and against the corpus. In order to carry out this analysis, the data was normalised, meaning the discrepancy score for the entire corpus became a constant (zero). This Normalised Discrepancy Score (NDS) was used to measure the reconstructions against the corpus, i.e. the closer to zero the reconstruction is, the closer it is to the corpus. Table 10 summarises the findings.

Table 10: Comparison of the three reconstructions of 'In tower most high' to the corpus. Normalised Discrepancy Score (absolute difference from the corpus using the exploding algorithm) expressed in percentages.

Reconstruction	Medius	Countertenor	Tenor	Bassus	Mean
Rec A	5.54	5.15	12.31	5.03	7.0
Rec B	20.98	6.43	11.44	7.99	11.7
Rec C	11.41	7.48	3.86	6.05	7.2

The table shows how Reconstruction B was the furthest from the corpus, due in particular to a high rate of discrepancy in the Medius part. Reconstruction A shows more discrepancy in the Tenor, and C in the Medius parts. This empirical measure can be added to our more subjective aural and counterpoint-based judgements. Other relevant analyses can be carried out using the same data, e.g. comparisons using only pieces in high clefs or pieces that use imitation, thus allowing the reconstructions to be evaluated in different ways.

A closer look at the data helps understand how to improve Reconstruction A. For instance, voice crossings in the reconstructions versus the corpus are shown in Table 11. This shows the average of overlapping parts in the corpus versus each of the reconstructions. Naturally, this gives an overall idea of how the parts overlap in consort songs, but more minute comparisons can be made as necessary.

Table 11: Overlaps comparison between the corpus and the three reconstructions.

Parts	Average Overlap in Corpus (%)	RecA (%)	RecB (%)	RecC (%)
Bassus-Tenor	8.38	4.40	10.68	7.23
Tenor-Countertenor	23.58	48.78	17.69	7.14
Countertenor-Medius	14.67	17.38	29.56	11.47

The table reveals how the parts and ranges were interacting and where issues may be. For instance, Reconstruction A shows that the Tenor-Countertenor overlaps are very high (48.78 percent) compared to the corpus (23.58 percent); in fact, this reconstruction has the highest rate of overlaps between the Tenor and Countertenor by a large margin. As a consequence of this, the rate of overlaps in the Bassus-Tenor is very low. Ultimately, what the overlaps indicate is that the ranges of the parts need to be reworked. This data together with the data in Table 10 show a series of issues. First, there are three instances of the initial imitation motive, which means that one of the parts will not use imitation; this happens in other similar pieces by Byrd, e.g. in ‘O Lord how vain’ (BE15 no.8), the ascending motive in ‘Content is rich’ (BE15 no.17) is not present in the treble viol part. Looking at the ranges and the data it becomes obvious that the part without imitation should be the top one (Medius). The reason for this is that all the imitations start on the pitches F_3 or Bb_2, which are too low for this part. If the Medius does not imitate, then the bottom range for this part can be higher, thus avoiding too much overlap with the Countertenor (a fifth instead of an octave). The Tenor and Countertenor can then have more distinct ranges, or if they have similar ranges, they can have opposite tendencies (i.e. one more towards the bottom range and the other towards the higher range). This would resolve the very high rate of overlaps between these two parts (48.78 percent) and make this reconstruction even more similar to the corpus.

As can be seen, this mixed-methods approach to analysing reconstructions has produced a series of findings worthy of consideration. First, it has verified the validity of the sources of the reconstructions, in this case the Paston lute intabulations. Second, it has allowed for a more detailed study of the differences between the intabulations and the original parts, a process that accelerates the understanding of the reconstruction of this repertoire and allows for the documentation of specific idiosyncrasies. Third, the analysis has produced empirical data about the correct lute to be used for the reconstructions, clef systems, ranges, tendencies for voice crossings, as well as the measurement of how close the reconstructions are to the corpus. The final result is a process that assists in removing some of the guess work when doing reconstructions from tablature notation. More importantly, the work presented here can be further refined since the data can be approached in many different ways and new queries can be created to interrogate the corpus.

Considering that there are thousands of pieces that survive in tablature notation and how much of a blind spot this is for musicology, this method is a promising way to bring to the fore what is a comparatively seldom researched repertoire. Furthermore, the method can be used to analyse other features of the repertoire such as ornamented intabulations of vocal pieces, or to inform the creation of editions of more idiomatic genres such as Fantasias or Ricercare. Considering the fact that more and more scores are being made available online, as is the case with this study,[44] the scope of this work can be greatly augmented by studying other corpora as necessary for similar projects. This, in addition to the mentioned initiatives to automatically encode tablature, presents a healthy environment for this research; e.g. the corpus compiled for this research is being used to experiment with artificial intelligence which entails running learning algorithms through the corpus to create automated reconstructions for further study.[45] In addition, other developments such as the software application jSymbolic, are simpler to use for automatic extraction of statistical data from musical data,[46] although there might be the need to utilise score-based tools such as Humdrum to incorporate notational aspects (barlines, etc) of the score into analyses.[47] Ultimately, the intersection between traditional historical methods and state of the art advancements in music technology open the door for research into challenging areas that deserve scholarly attention.

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[1] All the printed and manuscript lutebooks in French tablature are now lost.

[2] Brett's seminal article remains the best summary on Edward Paston and his collection. See Philip Brett, "Edward Paston (1550-1630): A Norfolk Gentleman and His Musical Collection," *Transactions of the Cambridge Bibliographical Society* 4 (1964), 51-69. For more recent scholarship on the subject see Philip Taylor, "Music and Recusant Culture: The Paston Manuscript Collection and William Byrd's Songs," (PhD diss., Lancaster University, 2007).; and Hector Sequera, "Practice and Dissemination of Music in Catholic Networks as Suggested By the Music Collection of Edward Paston (1550-1630) and Other Sources," in *Networks of Music and Culture in the Sixteenth and Seventeenth Centuries: A Collection of Essays in Celebration of Peter Philips's 450th Anniversary*, ed. David Smith, and Rachelle Taylor (Aldershot: Ashgate, 2013), 215-29.

[3] For information on the lutebooks see Hector Sequera, "House Music for Recusants in Elizabethan England: Performance Practice in the Music Collection of Edward Paston (1550-1630)," (PhD diss., University of Birmingham, 2010).; and Stewart McCoy, "Lost Lute Solos Revealed in a Paston Manuscript.," *Lute: Journal of the Lute Society* (1986): 21-39.

[4] The 35% is assuming there are 41 consort songs by Byrd and 15 we are trying to reconstruct using the methods mentioned in this article. To see the published consort songs, see Philip Brett, ed. *The Byrd Edition (Vol. 15),* Great Yarmouth: Stainer & Bell Ltd, 1970.

[5] Paul Doe, ed. *Elizabethan Consort Music I* (London: Stainer & Bell, 1979).

[6] One of the fantasias appears in 'A candle in the dark: Elizabethan Consort Song & Consort Music,' The Newberry Consort, 2000; and 'Armada: Music from the courts of Philip II and Elizabeth I,' Fretwork, 2000.

[7] Two other complex reconstruction contributions are those by Ian Payne. See Ian Payne, "Recomposition and Rearrangement in William Cobbold: In Bethlehem Town," *The Musical Times* 143 (2002), 42-55., and "New Light on 'New Fashions' by William Cobbold (1560-1639) of Norwich," *Journal of the Viola da Gamba Society* 30 (2002), 11-37. The latter also addresses the issue of reconstruction vs re-composition, an issue that affects aspects of the present work but that is not the focus of this article.

[8] Roger Bray, ed. *Robert Fayrfax: Regali, Albanus and Sponsus Amat Sponsam, Vol. 53* (London: Stainer & Bell, 2010).

[9] The last section of the Agnus Dei (*Dona nobis pacem*) also survives in GB-Lbl Add. MS 34049.

[10] For instance, Tudor Partbooks created reconstructed and restored facsimiles of the Baldwin and Sadler sets of partbooks. Visit the Tudor Partbooks website for more information: http://www.tudorpartbooks.ac.uk/

[11] In particular the reconstruction work done by groups in the AHRC funded project *Tudor Partbooks*, led by Magnus Williamson: http://www.tudorpartbooks.ac.uk/
[12] Tuomas Eerola, and Petri Toiviainen, *Midi Toolbox: Matlab Tools for Music Research* (Jyväskylä, Finland: University of Jyväskylä, 2004). See https://www.jyu.fi/hytk/fi/laitokset/mutku/en/research/materials/miditoolbox
[13] See Jane Bernstein, "The Chanson in England: A Study of Scores and Styles" (PhD, University of California, 1974), 163-226.
[14] The lute chosen to create an intabulation depends on the clef system and range of a vocal/instrumental polyphonic piece. Naturally, one can create an intabulation for any lute size and then perform the music on a different lute size. The most detailed historical account of this practice appears in Bermudo, Juan. *"On Playing the Vihuela" From Declaración De Instrumentos Musicales (Osuna, 1555)*. Translated by Dawn Espinosa. Lexington, VA: Lute Society of America, 1995.
[15] The hexachord with a sharp is the so called *ficta* hexachord in which *Ut* is placed in pitches other than C, F, or G. See Stefano Mengozzi, *The Renaissance Reform of Medieval Music Theory: Guido of Arezzo Between Myth and History* (Cambridge: Cambridge U. Press, 2010), 94-96. A seminal study on hexachordal transposition, particularly on the use of the *coniuncta*, is Oliver Ellsworth, "The Origin of the Coniuncta: A Reappraisal," *Journal of Music Theory* 17, no. 1 (1973), 86-109.
[16] There are instances of notes from the singing part appearing in the next part down, but the full part is never included. See the section 'cantus contamination' in Stewart McCoy, "Lost Lute Solos Revealed in a Paston Manuscript.," *Lute: Journal of the Lute Society* (1986), 25-31.
[17] The issues with the reconstruction of English polyphony, its history and historical examples are addressed in Judith Blezzard, "Reconstructing Early English Vocal Music: History, Principle and Practice," *The Music Review* 45 (1984), 85-95.
[18] See previous footnote.
[19] Brett reconstructed this piece because he had more sources to complete the work. 'O God, but God' survives in GB-Lbl Add. MS 15117 as a lute song with accompaniment, it also survives in GB-Lbl Add MS 30485 with all parts in keyboard score. These two in addition to the tablature in Paston's 31992 and the countertenor part in GB-Ob MS Mus. Sch. e. 423.
[20] Philip Brett, ed. *The Byrd Edition, vol 15,* (Great Yarmouth: Stainer & Bell Ltd, 1970), viii. For more information on the developments of Brett's Byrd Edition see Philip Brett, "Editing Byrd-1," *The musical times* 121/1650 (1980), 492-495.
[21] Philip Brett, ed. *The Byrd Edition, vol 15,* (Great Yarmouth: Stainer & Bell Ltd, 1970), ix-x.
[22] These group of pieces was brought to my attention by Andrew Johnstone.
[23] For more information on OMR see Ana Rebelo*, et al.*, "Optical Music Recognition: State-of-the-art and Open Issues," *International Journal of Multimedia Information Retrieval* 1, no. 3 (2012).
[24] For information on MEI see: https://music-encoding.org; for Auruspix see: http://www.aruspix.net; for ECOLM see: http://www.ecolm.org
[25] The project connects to other funded research. For more information visit: http://digitalduchemin.org/about/
[26] Andronikou suggests that typesetting of the lutebooks could have been done under the supervision of Ottaviano di Amadio (G. Scotto's cousin) thus justifying the errors. See Niki Andronikou, "The Lute Music of Melchiore De Barberiis (1546–1549) With Specific Reference to Books V, IX and X," (PhD diss., University of York, 2012), 33.
[27] Jeremy L. Smith, *Thomas East and Music Publishing in Renaissance England* (Oxford: Oxford University Press, 2002), 86.
[28] To have an idea of surviving English lute manuscripts see Julia Craig-McFeely, "English Lute Manuscripts and Scribes," (PhD diss., Oxford University, 1994).
[29] For examples on the functions and capabilities of these tools, see Tuomas Eerola and Petri Toiviainen, *MIDI Toolbox: Matlab Tools for Music Research* (Finland: Department of Music, University of Jyväskylä, 2003). The Levenshtein Distance has found application mainly in computer science, music, and linguistics. One of the seminal articles on its use in music is Marcel Mongeau, and David Sankoff, "Comparison of Musical Sequences," *Computers and the Humanities* 24, no. 3 (1990), 161-75.
[30] The only other surviving version of the piece is in Harvard College Library, Cambridge, Mass., MS Mus. 30, which was not available for inspection at the time of this writing.
[31] Ed W. Large, "Dynamic programming for the analysis of serial behaviors", Behavior Research Methods, Instruments & Computers, vol. 25 no. 2, 238-241. For the code, see https://www.jyu.fi/hytk/fi/laitokset/mutku/en/research/materials/miditoolbox.
[32] Some lute sources include a line after a cypher indicating the desired duration for a particular note; the Paston sources do not make use of this feature. Instead, the Paston lutebooks sometimes include dots within the tablature staff to indicate either a rest or the holding of a note. However, this is done only for full chords and not individual notes and it is not quite clear whether to hold or stop during these instances.

[33] To clarify, music in the Great Compass is always set for a lute in G in the Paston sources, since the range is from G_2 to G_5. The evidence from the Paston sources suggests that his instruments were of six courses, i.e. with no extra bass strings to extend the lower range.
[34] This piece has by far the highest substitution rate, the mean for the corpus is 5.93 percent with most pieces under two percent.
[35] The top reconstruction (Tenors I and II and Bass Viols) is from the excellent reconstruction work in Paul Doe, ed. *Elizabethan Consort Music I* (London: Stainer & Bell, 1979), 5-7.
[36] The epistle to the reader in William Byrd, *Psalmes, Sonets, & Songs of Sadnes and Pietie* (London: Thomas East, 1599).
[37] Thanks to Andrew Johnston and Magnus Williamson for providing reconstructions of Byrd's 'In tower most high' for this study.
[38] This adds to a total of forty pieces because three out of five parts in 'O God, but God' were reconstructed by Brett, which means that it is not possible to obtain the original clefs.
[39] My gratitude goes to Andrew Johnstone and Magnus Williamson for sharing their reconstructions to be analysed together with mine.
[40] A lute in D implies a hexachord starting in D with one sharp, as mentioned by Petrus Palma in his *Compendium de discantu mensurabili.* Such a hexachord appears in Paston sources such as GB-Ob MSS Tenbury 1469-71. For a list of such pieces see Hector Sequera, "House Music for Recusants in Elizabethan England: Performance Practice in the Music Collection of Edward Paston (1550-1630)," (PhD diss., University of Birmingham, 2010), 143-48.
[41] Philip Brett noticed this and published a table with the organization of the pieces in Philip Brett, "Pitch and Transposition in the Paston Manuscripts," *Sundry Sorts of Music Books: Essays on the British Library Collections* (1993), 106-7.
[42] In fact, this was one of Brett's mistakes as he assumed that all the pieces in the Paston lutebooks were arranged for a lute in G. This creates unattainable key signatures outside of the hexachordal key signatures. See Philip Brett, "Pitch and Transposition in the Paston Manuscripts," *Sundry Sorts of Music Books: Essays on the British Library Collections* (1993), 96-98.
[43] The exploding functionality in Sibelius can be accessed by going to Note Input/Arrange/Explode. This is for Sibelius 8 but it is very similar for other versions.
[44] The scores are available at the Harvard Dataverse: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/HT6IVU
[45] This new work is in early stages and is being done in collaboration with Reinier de Valk. For more information see Rainier de Valk, "Structuring Lute Tablature and Midi Data: Machine Learning Models for Voice Separation in Symbolic Music Representations," (PhD diss., City University of London, 2015).
[46] jSymbolic was primarily designed by Cory McKay. More information can be found at: http://jmir.sourceforge.net/index_jSymbolic.html
[47] See David Huron, "Music information processing using the Humdrum Toolkit: Concepts, examples, and lessons". Computer Music Journal, (2002), vol. 26 no. 2, 11-26 and http://www.humdrum.org/Humdrum/